EARLY STAGE BUILDING ENVIRONMENTAL ANALYSIS
CASE STUDY OF A LARGE RESIDENTIAL COMMUNITY IN INDIA

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ABSTRACT
Building orientation, massing and façade design has a large influence on the indoor environment, occupant well-being and the energy footprint of the building. And simulations performed in concept design phase yield effective design solutions as they influence early design decisions.

This paper presents a case study of a large government residential community located in New Delhi, India. At the onset of the project, a multitude of simulations were undertaken to assess and integrate passive design solutions. The climate and the micro-climate of the site were taken into consideration. A limited construction budget meant that efficient design strategies had to be employed to accommodate a large number of dwelling units without compromising on the indoor quality of the units.

The methodology involves a new environmental analysis tool “Ladybug” to find out the optimum shading for the fenestration considering solar irradiation and Dry bulb Temperature, and daylight analysis for spaces in terms of efficient visual environment. Another software named DIVA is used for daylight analysis. This paper contains the analysis methodology with the new tools and discusses the possibilities and capabilities for some of the features: the “sun path tool”, “Psychrometric Chart”, “Wind Rose” and other tools. Through DIVA, various daylight metrics were evaluated and compared for the interior spaces for the selection of optimum fenestration design in terms of better visual quality. The results shed insight for new analysis methods for environmental design and highlight its role in early stage architectural design.

INTRODUCTION
Climate analysis, particularly shading and thermal control has long been used to devise passive design solutions in architectural design. Specially, in case of medium level government housing projects in India, where mechanical cooling and heating are generally not options. Passive strategies help save energy and benefit a wide range of buildings. To start out, some case studies are listed and discussed for selecting the appropriate passive strategies for similar climate types in India. (see Figure 1)

Various methodologies and design tools such as Mahoney Tables (Koenigsberger, et al, 1973), Eco Charts (Krishan, et al, 2001) and computer based analysis such as Autodesk Ecotect have been used to inform the early stage design of buildings. In recent years, integrated and open source climate design tools such as Ladybug and Diva, plug-ins for Grasshopper and Rhino have been developed. These tools help realize integrated building performance solutions at an early stage.

The project being studied is a 277 unit housing complex for BSES, Rajdhani Power Ltd.- a public private partnership (see Figure 2). The project is located on a 6.7 acre site in Janakpuri, East Delhi. The project consists of 4 towers with about 67 % of the site dedicated to green spaces, rainwater harvesting and solar power generation. Of the 277 units, there are 91 one bedroom units, 129 2 bedroom units and 57 three bedroom units.

Ladybug, a free and open source, developed by Mostapha Sadeghipour Roudsari, is a customizable environmental plug-in for Grasshopper for Rhino that by virtue of working in the 3D modelling interface of Rhino/Grasshopper, simplifies the process of analysis by automating and expediting calculations. Due to its integration with grasshopper’s parametric tools; there is instantaneous feedback on design modifications, making the analysis highly interactive.

Diva, developed by Solemma, combines Daysim, Radiance and EnergyPlus into a daylight simulation plug-in for Rhino.
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<th>PROJECT Architect</th>
<th>LOCATION</th>
<th>CLIMATE METHODOLOGY</th>
<th>DESIGN STRATEGIES</th>
<th>DAYLIGHTING</th>
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<td>Faridabad, UP 28.4211 N, 77.3078 E</td>
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<td>Over-hanging and louvre combination</td>
<td>Double height living spaces around the courtyard</td>
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<td>New Delhi, Delhi 28.6139 N, 77.2090 E</td>
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<td>Hexagonal Courtyards : Windows and ventilators combination, interconnected with courtyards, aid in cross ventilation, both in rooms as well as between the courtyards</td>
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<td><strong>COMFORT ACHIEVED- Medium-level equilibrium in terms of thermal and visual comfort</strong></td>
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<td>INTEGRATED RURAL ENERGY PROGRAMME TRAINING CENTRE; Manmohan Dayal</td>
<td>Delhi, Delhi 28.6139 N, 77.2090 E</td>
<td>Combination of Mahoney Tables &amp; other climate visualization charts</td>
<td>Chajjas (overhangs) of appropriate depth on south side protect from summer sun, yet allow winter radiation to penetrate in</td>
<td>Courtyards used as microclimate modifier</td>
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<td>Vertical and Horizontal Louvres</td>
<td>Horizontal and vertical louvres prevents the heat from the S-E/N-W sun and helps for cross ventilation</td>
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<td>2.1m wide corridors shade 75% of wall area</td>
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<td><strong>COMFORT ACHIEVED- 6-7 C lower room temperatures achieved in summer and winter room temperatures raised by about 5 C than in conventional building</strong></td>
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<tr>
<td>HILL COUNTY SEZ OFFICE COMPLEX; SOM, NY</td>
<td>Hyderabad, AP 17.3700 N, 78.4800 E</td>
<td>Ecotect and Radiance simulations</td>
<td>Vertical Louvre/ Jali attached at angles particular to each façade orientation</td>
<td>Courtyards and slim slab spans, combined with operable windows allowed for cross ventilation; if and when required.</td>
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<td>Building stepped massing to allow for self shading on South and West facades</td>
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<td><strong>COMFORT ACHIEVED- 88.4% annual average shading</strong></td>
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METHODOLOGY AND DISCUSSIONS

The methodology for the environmental analysis of the proposed housing has three steps: climate, shading and daylight analysis. For the climate analysis, various environmental parameters like Dry Bulb Temperature (DBT), Relative Humidity (RH), Solar Radiation, Wind (velocity and direction) are visualised for entire year and critical months representing the extreme conditions are evaluated in terms of swings, ranges, time period and frequencies.

Psychrometric charts were studied for the evaluation of existing comfort periods, suitable clothing value, wind speed and other parameters were tested for enhancing the comfort band through passive means in the “Ladybug Psychrometric chart” component. Ladybug’s environmental tools were compared to existing methodologies like Koenigsberger’s “Mahoney Table Analysis” (Koenigsberger, et al, 1973) and Arvind Krishan’s “Eco Chart” (Krishan, et al, 2001).

In shading analysis, sun path study is conducted with respect to various other environmental factors like DBT and solar radiation to find out the optimum depth of shade projection for the fenestration. Ladybug’s shading design tools like “Ladybug_ShadingDesigner” and Ladybug_Comfort Shade Benefit Evaluator” have been used to find out the solar cut off angles.

Daylight analysis was performed in “DIVA for Rhino” plug-in. Daylight metrics, both static and climate based, such as Daylight Factor (DF), Illuminance levels, Spatial Daylight Autonomy (sDA) and Annual Solar Exposure (ASE) were calculated to ensure better visual comfort with respect to various shading depths.

Climate Analysis

As per National Building Code, India, 2005 (NBC), the climate of New Delhi falls under the “Composite” type. The definition of this climate as given by NBC is- “A climatic zone that does not have any season for more than six months” (NBC, 2005). The characteristics for this climate are rightly described by Mili Majumdar (Majumdar, 2001) as:

“Very large climatic swings over the year, i.e. very hot and dry period of almost two and a half months and a colder period of a shorter duration. The hot and dry period is followed by a hot and humid monsoon period of about two months with intervening periods of milder climate.”

Table 1

Climate classification for India (adapted from Table 2, Classification of Climate, Part 8, NBC, 2005)

<table>
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<tr>
<th>SL NO.</th>
<th>CLIMATIC ZONE</th>
<th>MEAN MONTHLY MAXIMUM TEMPERATURE (C)</th>
<th>MEAN MONTHLY RELATIVE HUMIDITY PERCENTAGE</th>
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<tbody>
<tr>
<td>i)</td>
<td>Hot-Dry</td>
<td>above 30</td>
<td>below 55</td>
</tr>
<tr>
<td>ii)</td>
<td>Warm-Humid</td>
<td>above 30</td>
<td>above 55</td>
</tr>
<tr>
<td>iii)</td>
<td>Temperate</td>
<td>between 25-30</td>
<td>below 75</td>
</tr>
<tr>
<td>iv)</td>
<td>Cold</td>
<td>below 25</td>
<td></td>
</tr>
<tr>
<td>v)</td>
<td>Composite (New Delhi)</td>
<td>&gt;30 for the months of April to October, between 25-30 for March and November and &lt; 25 in the months of December &amp; January.</td>
<td>Varies</td>
</tr>
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</table>

Using Ladybug’s “Ladybug_3D Chart” component hourly data for Dry Bulb Temperature, Global Horizontal Radiation and Relative Humidity were visualized for various months.
As observed from Figure 3-5, the DBT and solar radiation are very high for the month of April to September compared to rest of the year. The peak DBT for these months is 45 °C and the minimum is 5°C. DBT swings for these months are from 38.5°C (Monthly mean Max. in June) to 22.8°C (Monthly mean Min. in April). The RH varies throughout the year, it is maximum (>70%) in the month of April to June, October and November. On an average it remains below 50% for the rest of the year. The global Horizontal Radiation is maximum in the month of May and June (avg is > 800 Wh/m²).

Psychrometric Analysis

Psychrometric analysis was carried to calculate the comfort potential for this climate type. The “Ladybug_Psychrometric Chart” component evaluates a set of DBT and RH in terms of indoor comfort. An EnergyPlus format weather file (.epw) was fed as an input. The comfort band was evaluated for Predicted Mean Vote (PMV) model developed by P.O. Fanger (Fanger, 1970). The range of comfort is generally accepted as PMV between -1 and +1, and “Ladybug_Psychrometric Chart” follows these values for prediction of comfort band. Ladybug has an option to modify weather parameters and applicable passive strategies to increase the comfort band. The default values for parameters like Mean Radiant Temperature (MRT), wind speed, metabolic rate and clothing value for “Ladybug_Psychrometric Chart” component are 23°C, 0.05 m/s (typical for indoors), 1 met (for a seated person) and 1 clo value (assuming a person wearing three piece suit).

Figure 6 shows the comfort band for the whole year and comfort is achieved for 19% annually, with default set of values. As identified earlier, the critical time for analysis is considered from April to September. Further studies were conducted with varied parameters for daytime hours (08:00am to 06:00pm) to increase the comfort band. For the critical period daytime hours, the comfort is evaluated ≈9% annually.

Various iterations (see Figure 7-9) were made to increase the comfort band as shown in Table 2.

### Table 2

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<tr>
<th>PARAMETER SPECIFICATION</th>
<th>COMFORT PERCENTAGE</th>
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<tr>
<td><strong>Analysis Period:</strong> April to September, 08:00am to 06:00pm.</td>
<td><strong>Base Case:</strong> All Default values for Wind Speed (0.05 m/s), Mean Radiant Temperature (230°C), Metabolic rate (1) and Clothing value (1). 9%</td>
</tr>
<tr>
<td><strong>Wind Speed:</strong> from 0.05 m/s to 3 m/s</td>
<td>26%</td>
</tr>
<tr>
<td><strong>Clothing value:</strong> change from default of 1 (three piece suit) to 0.3 representing a typical person wearing light trousers and sleeves (clothing value has been referred from Table 46% of CIBSE Guide A)</td>
<td><strong>Passive Strategy:</strong> Thermal mass + Night Ventilation 93%</td>
</tr>
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</table>

From this analysis, the comfort band could be significantly increased (from 9 to 93%) in the critical time period by adapting simple passive means.
Figure 9: Psychrometric chart showing the comfort band with increased wind speed of 3m/s and clothing value of 0.3 and Thermal mass + Night Ventilation

Wind Rose Analysis
The “Ladybug_Wind rose” component is an advanced version of traditional wind rose diagrams. Apart from showing the wind speed & direction, it has further options to overlay hourly data in terms of DBT, RH, etc. Ladybug has the capability of applying any condition/constraints to filter out data from any given set. For example, the user can feed a condition like wind speed of above 3 m/s and/or DBT above 33°C and/or RH below 75%, and so on. This feature is thus becomes more helpful in terms providing useful and sometimes critical insight for ventilation studies.

In context to the proposed BSES housing, a detailed wind rose study was conducted, to gain information on wind speeds, frequencies/duration, direction and applied conditional temperature. First an annual windrose without any conditions applied is shown. This is a traditional wind rose showing only speed and direction. Next, a speed condition of more than 3 m/s, a DBT of greater than 33°C, both wind speed and DBT conditions were applied for whole year, and only for critical period (April to September) are applied respectively. (see Figure 10-14)
Figure 14 Wind Rose for critical period: Condition 4: Speed > 3 m/s and DBT < 33°C

From Figure 10 and 11 it is observed that, the wind is available from NW, E and SE orientations. Wind speed > 3 m/s is predominantly from the NW orientation. Figure 10 and 11 shows the temperature overlay upon the speed of > 3m/s. It can be seen that the wind from NW is accompanied with higher temperatures (> 33°C). However, for the critical period, the wind at lower temperatures (< 33°C) is also from the NW orientation, but the frequency is quite low, i.e., only around 162 hours. From this analysis it can be concluded that wind driven natural ventilation can be effectively used for night time cooling and structural cooling.

Shading Analysis

After finishing the site analysis, we performed a detailed unit level analysis.

Three different Ladybug components were used for shading analysis of the proposed residential towers: shading period selection using “Ladybug_Sunpath” component, form finding using “Ladybug_ShadingDesigner” and shade benefit through “Ladybug_Comfort Shade Benefit Evaluator”. Generally shading period selections require solar cut off dates based on critical hours. This can be based on simple methods like solar radiation and/or cooling degree-days and/or more advanced concepts like carrying out thermal simulations. However, through “Ladybug_Sunpath” component it is possible to select shading period based on multiple criteria like, cut off dates for temperature or radiation thresholds. Ladybug offers many options to carry out sun path study in terms of data visualization and offers direct link between shading period selection and form finding process for shades. In addition, it has a component that evaluates benefits of any given shade in terms of comfort temperature.

Through “Ladybug_Sunpath” component it is possible to overlay hourly data for temperature and solar radiation at each sun position. In our study, we applied a constraint of DBT and solar radiation to select appropriate shading period. From the climatic hourly data set, it was identified that a solar radiation of more than 600 Wh/m² is to be fixed as upper limit for which shading is required. In addition a DBT of more than 33°C is to be avoided. This threshold has been adopted from NBC, 2005, which says temperature above this limit is uncomfortable for Non-Air conditioned buildings in India.

Using “Ladybug_ShadingDesigner” it is possible to directly extract the solar cut off angles from the sunpath component and is applied for sizing of shades for all type of fenestration. Unlike existing sunpath tools, in which HSA (Horizontal Shadow Angle) and VSA (Vertical Shadow Angle) needs to be calculated and then shading is designed using these angles separately, Ladybug exchanges “Sun vectors” to automatically design overhangs and/or vertical fins. Ladybug also has options for selecting from various combination of shading in terms of height restrictions, or number of shades. The analysis was performed for three sets of conditions, which are, 1) Global Horizontal Radiation > 600 Wh/m², 2) DBT > 33°C and 3) a combination of condition 1 and 2, where GHR is > 600 Wh/m² and DBT > 33°C. These conditions are visualized in Figure 15.

This analysis was used to calculate the size of the overhang. This resulted in a 3.25 m depth overhang. Since the required depth is very large, deep balconies and horizontal louvres were designed to cut off the high sun angles; relegating the need for additional shading devices. (see Figure 16)

Daylight Analysis

“DIVA for Rhino” has been used for daylight analysis. Three metrics were evaluated: Daylight Factor, sDA and ASE. Daylight Factor gives insight into level of daylight for interior spaces and is a frequently used metrics in daylight analysis. According to IES LM-83, ASE is defined as the percentage of square footage that has direct sunlight for more than 250 hours a year. And sDA is the percentage of area that is about 30 fc for 50% of the time. (IES LM-83-12, 2012)

Two cases, one without any shading and the other with proposed shading (as evaluated from Ladybug_Shading Designer) were evaluated for a typical room as highlighted in figure 15. From figure 15 it can be observed that, in both the cases Daylight Factor is more than 5%, which exceeds the recommended levels in residential spaces, as indicated by SP 41, 1987. Also sDA is 100% in both the cases, however ASE in both the cases is well above (54% & 24%) the IES recommended value (13%). (see Figure 16)
Conventional Method
Shading Period: Solar cut off dates – VSA – Overhang Size

Proposed Method
Shading Period: Sun Vectors – Overhang Size

Apply conditions:
DBT >33°C
Global Horizontal Radiation > 600 Wh/m²

Shade Benefit Analysis

Condition 1: Global Horizontal Radiation > 600 Wh/m²

Condition 2: Dry Bulb Temperature > 33°C

Condition 3: GHR > 600 Wh/m² and DBT > 33°C

Figure 15: Shading Analysis and Final form of shade
CONCLUSIONS
From our study we found that the software was intuitive and easy to use. The highly visual interactive results help architects in converting technical information into design solutions. Since the tools used in this paper plug-in to a 3D environment, namely Rhino, that architects already use, the need for additional analysis models is reduced. And so, design solution making can be undertaken in real-time.

On this project, these tools were used to find out optimal shading solutions, while maintaining acceptable daylight levels.

REFERENCES
SP 41- Handbook on Functional Requirements of Building (other than Industrial Building) 1987.
IES LM-83-12, 2012. Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE), STANDARD by Illuminating Engineering Society, USA.
Roudsari, M.S., Ladybug Workshop @PennDesign April 2014. Youtube Video Tutorials, https://www.youtube.com/playlist?list=PLkJfDmSc5OrzBgdPWQB7rbqFyeWpbx1aN